United States Department of Agriculture

Soil Conservation Service

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ENVIRONMENTAL TECHNICAL NOTE NO. 57

SUBJECT: WQP - CONSERVATION PLANNING FOR WATER QUALITY CONCERNS, TOXIC ELEMENT - SELENIUM

Purpose. To transmit the above named technical note.

Expiration date. When contents have been noted.

Filing Instructions. File in Environmental Technical Note Binder.

Explanation. Attached is paper developed by the WNTC Water Quality Staff concerning the toxic element Selenium (Se). It discusses the distribution of Se in the west; its toxicity to humans, livestock, fish and wildlife; and solutions to manage Se. This paper can be used to assist in planning alternative Resource Management Systems for farmers and ranchers.

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March 26, 1993

WATER QUALITY TECHNICAL NOTE NO. W-1
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SUBJECT: WQP - CONSERVATION PLANNING FOR WATER QUALITY CONCERNS, TOXIC ELEMENT - SELENIUM

Purpose. To transmit the above named technical note.

Effective Date. When received.

Filing Instructions. File in Technical Note binder - Water Quality Section.

Background. The WNTC mission for "quality technology for resource decisions" has prompted the Water Quality Staff to investigate and prepare a technical note on the toxic element selenium (Se). The information in the note will provide planners with one more tool for helping plan alternative Resource Management Systems for farmers and ranchers. Make it a part of your FOTG.

Planning Considerations. This paper discusses the distribution of Se in the West; it's chronic and acute toxicity; and conservation practices to control Se contamination and deficiency.

There may be a Se hazard if you are in an area where Cretaceous or Jurassic shale outcrops, annual precipitation is less than 20 inches, seleniferous vegetation such as loco weed (Astragalus) is present, there is coal, bentonite, or uranium mining, or ground water or surface water quality records indicate Se contamination.

Acute poisoning from Se first emerged as a problem with livestock grazing in the West, but now it is also known to poison fish and wildlife in ponds and wetlands, particularly where drainage from irrigation supplies much of the water and Se is bio-accumulated in the food chain.

-MORE-

DIST:
S (West)
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Consider the Se hazard to man, livestock, fish and wildlife when you assist a farmer or rancher to build a reservoir, plan a grazing system, improve an irrigation or drainage system, construct a pond or wetland, treat a saline seep, treat a mine tailing, or evaluate a domestic well.

Consider conservation practices or auxiliary actions that can be taken to prevent chronic or acute poisoning of humans, livestock, fish, or wildlife when you develop a plan for a farmer, rancher or community. In some sections of the country you may be planning to overcome dietary Se deficiency.

HOWARD R. THOMAS
Head, Water Quality Staff

United States
Department of
Agriculture

Soil
Conservation
Service

West National
Technical Center

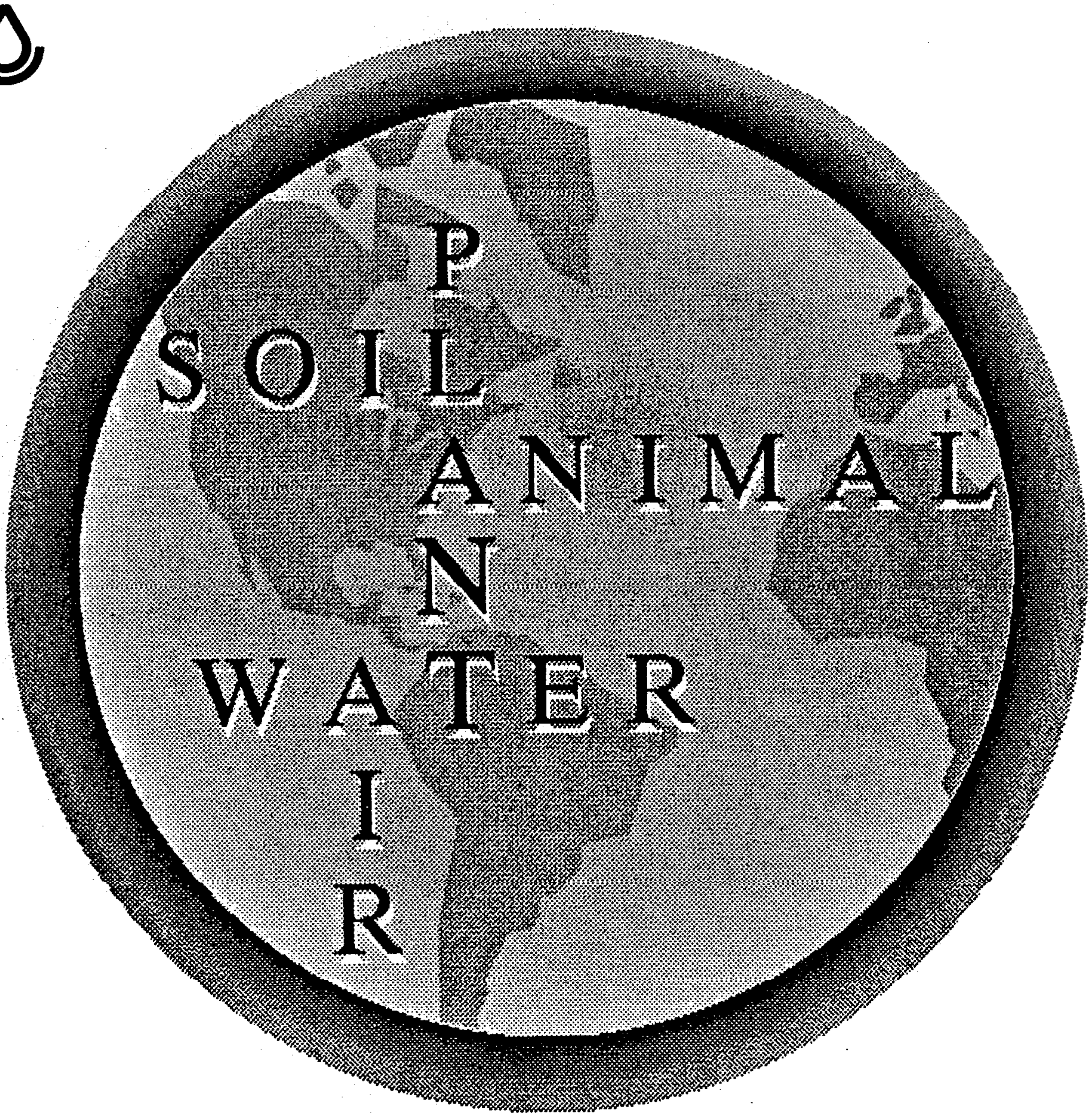
Portland, Oregon

March, 1993

Technical Note

Conservation Planning for Water Quality Concerns
Toxic Element - Selenium

Water Quality Series No. W1



WNTC - Quality technology for resource decisions

CONSERVATION PLANNING FOR WATER QUALITY CONCERNS
TOXIC ELEMENT - SELENIUM

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CONSERVATION PLANNING FOR WATER QUALITY CONCERNS
TOXIC ELEMENT - SELENIUM [1/]

NO SIMPLE ANSWERS TO SELENIUM

Selenium. Do you mean that element added to horse and sheep feed for healthy growth? Then I'm all for it, or do you mean, **Selenium**, that element that may deform and kill fish, wildlife, sheep, and horses. Then I'm against it!

Think of selenium (Se) as an "essential poison"! The difference is a very fine line, but like a lot of things in life on this planet, a little is very beneficial and vital, but too much is a killer. Eating too much contaminated fish and fowl or drinking contaminated water could be hazardous to your health.

How water is managed for irrigation is critical to the concentration of Se. Seepage and deep percolation of irrigation water can pick up large amounts of Se in certain areas. When irrigation drain water is allowed to evaporate and bio-concentrate Se in wetland areas, it is acutely toxic to fish and waterfowl.

This paper discusses the distribution of Se in the West; its toxicity to humans, livestock, fish and wildlife; and solutions to manage Se.

SELENIUM DISTRIBUTION IN THE WEST

Nature provides selenium (Se) in many geologic formations throughout the world, but it is most abundant in sedimentary rocks such as shale, sandstone, limestones, and phosphorite rock and soils derived from them. It is highly mobile and biologically available in arid regions having alkaline soils typical of the Western United States. A number of plants, such as loco weed have the ability to concentrate Se extracted from the soil into a biologically available form, which, when eaten is toxic to livestock. Selenium can also be mobilized or released from the soil by a crop-fallow management system or irrigation activities. Saline seeps developed in wheat-fallow areas of the plains from Texas to Canada may have high concentrations of Se. Seepage contaminates ground water and surface runoff. Surface and ground water contain varying amounts of Se - too much can be toxic to livestock, fish, wildlife, and humans.

1/ Prepared by John D. Hedlund, Water Quality Specialist, USDA-SCS, West National Technical Center, Portland, Oregon, January 1993.

From USGS ground water quality records at 100,400 sites, 1420 wells have been identified in the Western US where the Se concentration exceeds 10 ug/L. See Figure 1. Available ground water quality records indicate Se concentrations, but may not be all inclusive. Remember, a well is a sampling point in the water table, integrating water quality over a vertical range. A measurement in a lake, drain, sump, or stream integrates water from possibly hundreds of thousands of acres over depths of several tens of feet. Surface water quality sections at 24,700 sites were screened for Se. Figure 2 displays 600 USGS surface gaging stations in the West where the Se concentration exceeds 10 ug/L. Gary Conaway, Hydraulic Engineer at the WNTC compiled the information from USGS water quality records stored in CD-ROM files.

SELENIUM PROBLEMS AND SOLUTIONS

Water quality criteria from EPA 440/5-86-001: Total recoverable inorganic selenite criterion to protect freshwater aquatic life is 35 ug/L as a 24-hour average, and the concentration should not exceed 260 ug/L at any time. For inorganic selenate the acute toxicity to freshwater aquatic life occurs at concentrations as low as 760 ug/L. The U.S. EPA human health standard in 1992 for the ambient water quality for Se is recommended to be 50 ug/L. Check your state for its recommended health standard.

The concentration of Se in rivers, streams, lakes, and wetland areas is greatly increased by irrigation drainage return flow in certain areas of the West. Streams above irrigated areas in the Colorado River may have Se concentrations of less than 1 **microgram per liter (ug/L) or 1 part per billion (ppb)** while downstream from irrigated areas, the concentration may be greater than 30 ug Se/L. Drainage return flow from the Westlands Irrigation Project in California averaged 300 ug Se/L, and ranged from 160 to 1400 ug Se/L. Selenium was further concentrated in artificially created wetland areas by evaporation and bio-accumulation. Levels were high enough in plants and animals to cause mortality and impair reproduction of aquatic birds and fish.

The discovery of the dual role of Se as both an essential and potentially poisonous element in animal and human nutrition has created interest. In the West, Se should always be considered in conservation planning when determining the effects of alternative Resource Management Systems (RMS's).

Some of the activities are:

1. Avoid bio-accumulation of Se in shallow ponds and wetland areas to toxic levels to fish and wildlife.

2. Control livestock grazing of plants which accumulate Se to poisonous levels.

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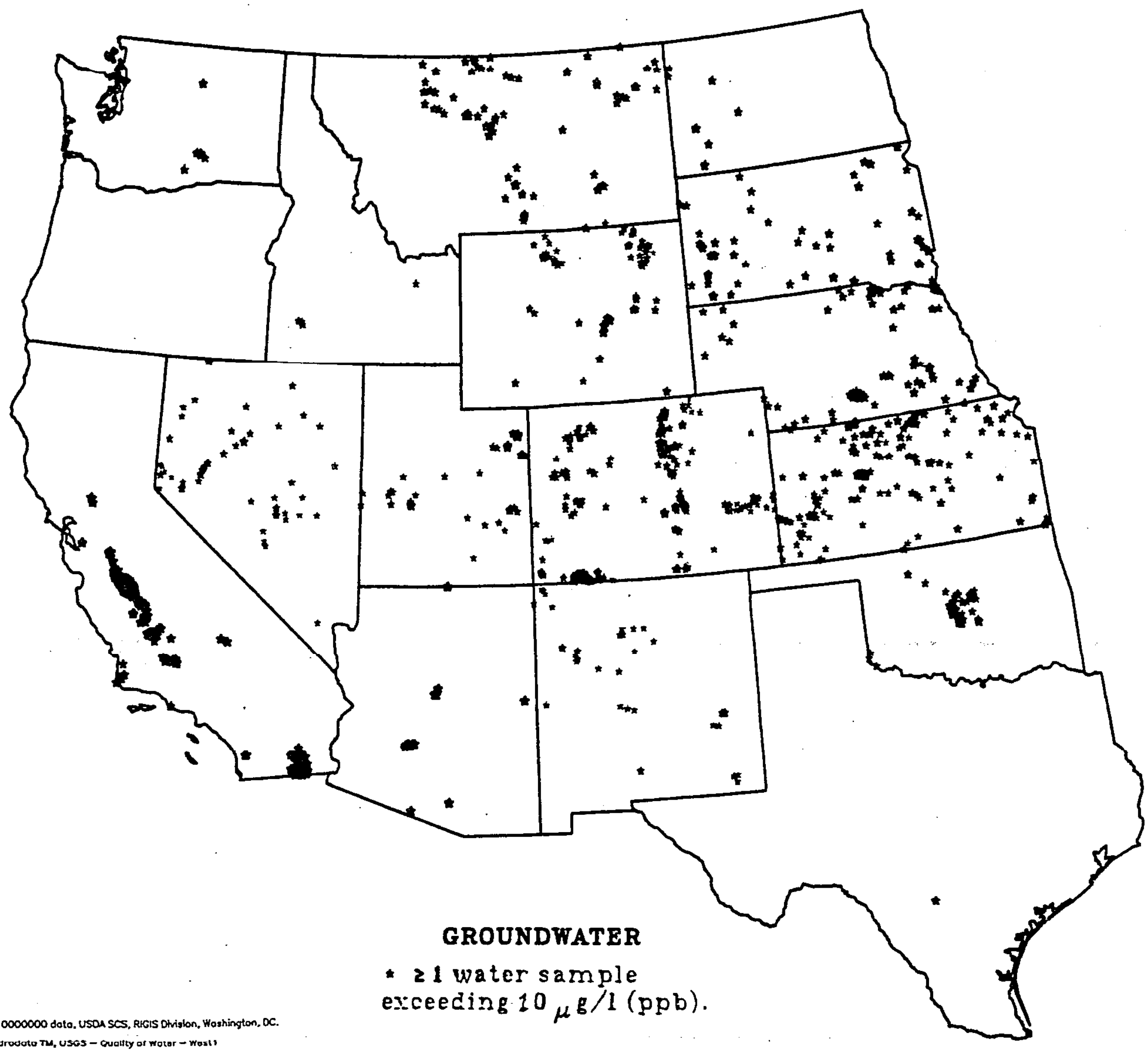
FIGURE 1: Selected Water Quality Monitoring Stations with Elevated Selenium



BASE MAP DATA SOURCE: 1:10000000 data, USDA SCS, RIGIS Division, Washington, DC.
SALINITY DATRA SOURCE: Hydrodata TM, USGS – Quality of Water – West 1 and 2. Earth Info, Inc., 1991.
DATA COMPILATION: USDA SCS–WNTC, Water Quality staff, Portland, OR 1992.
MAP CPMPILAION: GRASS–MAPGEN software, USDA SCS–WNTC GIS staff, Portland, OR 1993.

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FEBRUARY, 1993

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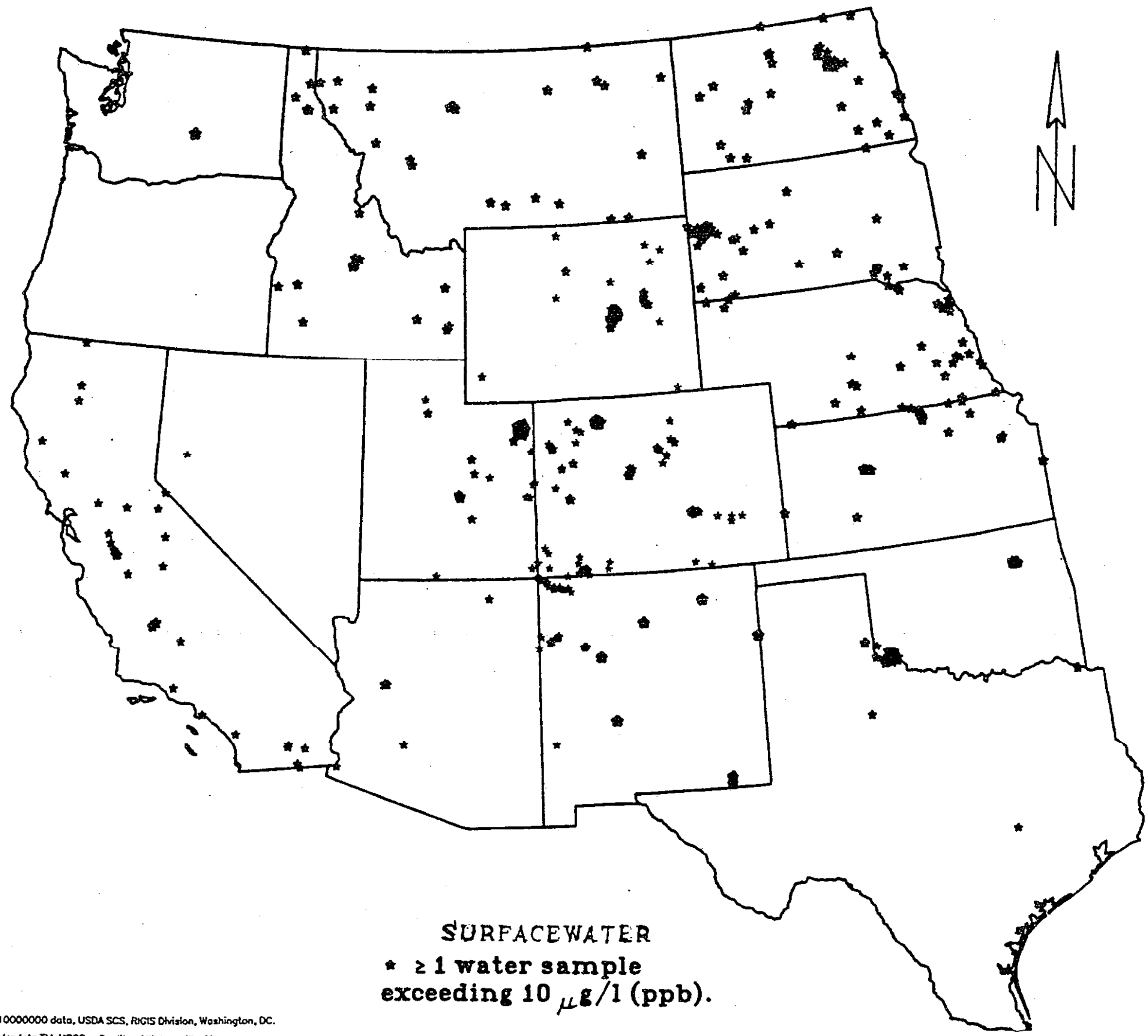
FIGURE 2: Selected Water Quality Monitoring Stations with Elevated Selenium



BASE MAP DATA SOURCE: 1:10000000 data, USDA SCS, RIGIS Division, Washington, DC.
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3. Identify safe and effective methods of increasing Se concentrations in plants in deficient parts of the nation.

4. Apply flexible wheat-fallow management systems in areas of saline seeps to reduce Se contamination of soil and water.

5. Reclamation and control of Se contamination of soils, surface water and ground water from uranium, coal, bentonite, and phosphate mining operations.

6. Minimizing deep percolation and seepage from irrigation, and manage drain flow containing high concentrations of Se.

Human Toxicity

Human toxicity from high levels of Se in diets derived from food grown on seleniferous soils is relatively rare. Toxic symptoms from drinking contaminated water is also relatively rare.

1. Adults in the U.S. consume approximately 160 ug Se/day. Daily recommended allowance is 50 to 200 ug Se/day (National Academy of Science, 1983). The 1992 Drinking Water Standards and Health Advisories place the **Reference Dose** (RfD) - daily exposure to the human population that is likely to be without appreciable risk of deleterious effects over a lifetime at **5 ug/kg/day** for a 70-kg adult.

2. Water. The 1977 Safe Drinking Water Act of U.S. EPA established an allowable standard for drinking water of 10 ug Se/L; The April, **1992 Drinking Water Regulations** and Health Advisories published by U.S. EPA place the Maximum Contaminant Level Goal (MCLG) and MCL **at 50 ug/L.**

3. In China no toxic symptoms were detected in individuals consuming up to 750 ug Se/day. However, individuals consuming 5000 ug Se/day or more had symptoms of hair and nail loss and skin lesions.

4. Water. A family in Durango, Colorado, including a dog, suffered hair loss, nausea, and fatigue by drinking water from a domestic well contaminated by Se. The Se concentration was 9,000 ug/L and the well was located in a shale and siltstone formation.

5. Drinking water from ponds, seeps, or creeks. A heading in the Sunday Oregonian, December 11, 1988, read, "Doctor learns of Se too late to save victim." Girard Perkins of Burns, Oregon died with every organ in his body, from his brain to his kidney, containing high Se counts, probably from drinking spring water polluted with Se.

6. If the diet does not supply sufficient Se, diseases such as Keshan (juvenile cardomystropathy) and Kaschin-Beck (chondrodystrophy in children) may occur.

Protecting the Human Environment

Drinking water should be tested to see if it meets the allowable health standard set by state water quality standards or 50 ug/L established by U.S. EPA. Most municipal systems have periodic tests and deliveries don't exceed these limits for any significant time periods. Remember, ground water supplies 100 million Americans with drinking water.

Rural domestic wells need testing also, particularly if any of the symptoms of Se poisoning occur such as hair and nail loss, nausea, skin lesions, and fatigue. Alternative solutions are drinking bottled water or treatment to remove Se.

Eating fish from water bodies with high concentrations of Se is permissible if the daily recommended allowance by EPA of 210 ug/day is not exceeded. Several ponds in the Colorado River Basin have Se warnings such as: "Due to the high level of Se in the fish of the lake, it is advisable not to eat any fish caught." State health advisories may recommend consumption of no more than 10 ounces of fish per week for adult males.

Domestic Livestock Toxicity

Symptoms of acute Se poisoning include anorexia, labored breathing, abnormal movement and posture, prostration, and diarrhea, which is followed by death in a few hours. Chronic Se poisoning of livestock produces anorexia, liver cirrhosis, lameness, hoof malformations, loss of hair, anemia, and emaciation (NAS-NRC,1976). Reduced reproductive performance is the most significant effect in livestock eating forages of 5 to 10 mg Se/kg dry weight (Olson, 1978).

1. **Deficiency** in Se is likely when the concentration in food is less than 0.05 mg Se/kg. Selenium deficiency causes white muscle disease in calves and lambs. Death losses occur. Selenium deficiency in livestock is more common around the world than toxicity.

2. **Sufficiency** in Se in livestock food is in the range of 0.1 to 1.0 mg Se/kg.

3. The **chronic toxicity** threshold for lab animals is from diets providing 4 to 5 mg Se/kg body weight of Se daily. The Food and Nutrition Board of the National Academy of Sciences (1980) has established 5 mg Se/kg as the critical level between toxic and non-toxic feeds.

4. Open-range grazing of primary Se-accumulator plants may produce **acute poisoning** to livestock - horses, cattle, and sheep.

This usually only happens during drought when plants that concentrate Se are grazed. Normally these plants are not palatable to livestock and have an offensive odor due to Se. The Great Plains from Texas to Canada have documentation of conditions leading to poisoning from consumption of Se-accumulator plants. Selenium concentrations in vegetation that cause acute poisoning, range between 400 and 800 mg/kg (Girling, 1984).

Protecting Domestic Livestock

Selenium deficiency in livestock diets can be overcome by adding feed supplements containing Se. Selenium fertilizer can be added to increase Se in crops grown on deficient soils. Some fertilizer materials may contribute Se for use by plants. Fertilizer made from rock phosphate may contain as much as 200 mg Se/kg. Liming acid soils was found to increase the uptake of Se by plants (Cary, 1967). Conflicting results are reported on Se solubility and changes in plant uptake due to adding lime, gypsum, sulfate, and phosphate. The contradictory effects can usually be explained by evaluating site specific information. Only two countries, New Zealand and Finland, have begun adding Se legally to fertilizers used for production of both forage and human food.

Selenium poisoning of livestock can best be controlled by proper grazing management. This would require the exclusion of livestock grazing on range where Se is concentrated in plants on seleniferous soils. Usually only during drought or when livestock are starving will they eat the normally non-palatable, acutely toxic Se-accumulator plants, such as loco weed; however, it has been found that some livestock have a greater propensity to ingest toxic plants than others. Chronic toxicity can be reduced by knowing the Se-accumulator plants and restricting grazing of them. Pest management to control or eliminate those plants which are Se-accumulators on rangeland is another possible treatment. Range seeding and alternative land uses should also be considered for these areas.

Testing water supplies for Se is another preventative measure to reduce the hazard of toxic poisoning of livestock. Alternative water sources for livestock may have to be found. If you are going to assist a farmer or rancher build a pond consider the Se hazard. Consider the factors of Se distribution: Is it located in an area of less than 20 inches annual precipitation, in an area with Cretaceous shale formations, is seleniferous vegetation present, or do ground water or surface water records indicate a Se hazard? If a Se hazard is identified, alternative sources of livestock water should be found.

Fish and Wildlife Toxicity

Toxicity varies for different forms of Se, animal species, duration of exposure, method of uptake, and other factors. In wetland areas, bio-accumulation and bio-magnification increase concentrations of Se in the food chain. Selenium is taken up by aquatic biota including phytoplankton, zooplankton, and insects which contribute to the diet of higher forms of wildlife. Dietary plant Se is readily absorbed by animals. Most of the Se (70-80%) is quickly excreted in the urine, breath, perspiration, and bile. The remaining Se becomes bound or incorporated into blood and tissue and is only slowly eliminated (Olson, 1978).

1. Selenium transfer in the food chain has caused Se toxicity in aquatic birds, not only as hatching deformity and death, but also as mortality of adult fowls. Hatchability of chicken eggs is reduced when dietary concentrations are 6 to 9 mg Se/kg.

2. Waterborne Se is acutely toxic to certain aquatic invertebrates at concentrations of 70 to 760 ug Se/L (U.S. EPA, 1980).

3. Waterborne Se is acutely toxic to certain fish. Ponds contaminated with Se from coal fly ash have caused reduced fish populations. Lemly (1985) found that Se contamination of 10 ug Se/L eliminated 16 of 20 fish species. Only carp, black bullheads, and mosquito fish were present throughout the study. Mosquito fish were the only fish found in Kesterson ponds during 1983-1985 because of Se contamination from irrigation return flow.

4. Several years of testing at the Monticello Ecological Research Station (MERS) have shown that adverse effects on bluegills may occur at Se concentrations as low as 2.5 ug Se/L in the water. Selenium is bio-accumulated and toxicity comes about through the food chain. Communications May 24, 1991, with Roger O. Hermanutz, Research Aquatic Biologist, MERS.

Protecting Fish and Wildlife

Selenium poisoning of fish and wildlife due to human activities affecting the biological availability of Se has been reported when wetlands or water bodies receive Se through subsurface agricultural irrigation drainage water or fly ash from coal-fired power plants. The most pronounced effect in wildlife species has been found in birds that fed regularly at Kesterson National Wildlife Refuge near Gustine, California. The solution at Kesterson has been to cut off the irrigation drainage flow and cover up the artificially created wetlands (evaporation ponds). In the San Joaquin Valley of California there are approximately 6850 acres of evaporation ponds for disposal of irrigation drain water, most with elevated concentrations of Se. Source control measures to reduce irrigation use include improved irrigation water management, crop management, alternative land use, selective land retirement, and alternative drainage disposal (reuse and agroforestry, for example).

TOTAL RESOURCE MANAGEMENT

A complete conservation management system which can control Se contamination as well as other problems of the soil and water, and protect the plant, animal, and air resources is called a **Resource Management System (RMS).** Table 1 displays options designed to protect soil, water, plants, and animals from Se pollution.

Table 1. Conservation practices and auxiliary actions to control selenium contamination or deficiencies

Conservation Practices and Auxiliary Actions	Soil Cond.	Water Quality	Plants Mgt. Nutr.	Animals Mgt. Health	Air
	Contaminants				
<u>Rural Domestic Water Supply</u>					
Well testing		x		x	
Water treatment		x			
Use bottled water		x			
Geologic invest.	x	x			
<u>Livestock-Se Deficiency</u>					
Feed Se supplements			x	x	
Apply Se fertilizer	x		x	x	
<u>Livestock-Se Poisoning</u>					
Proper grazing use			x	x	x
Livestock exclusion			x	x	x
Pest management			x	x	
Range seeding	x		x	x	x
Alternative land use			x	x	x
Test water supplies		x		x	
<u>Fish and Wildlife-Se Poisoning</u>					
Cut off irrig. drain flow		x		x	
Fill in ponds	x			x	
Irrig. water mgt.		x	x	x	
Drainage mgt.		x	x	x	
Crop mgt.		x	x	x	
Cons. cropping seq.	x		x		
Alternative land use		x	x	x	

A conservation management system may include practices such as irrigation water management, changing to a cropping sequence which reduces saline seep conditions, proper disposal of irrigation drain water, planned grazing systems and proper grazing use, pest management of Se-accumulator plants, and domestic well testing. Reducing contamination to an established quality criteria will be the goal.

The RMS will consider other soil and water problems and the plant community condition for livestock forage and food production goals, the health of the animal kingdom for fish and wildlife, and the quality of the water for domestic, livestock, and wildlife use. RMS's should be planned with the farmer or rancher to protect their domestic water supply, prevent livestock poisoning, and prevent poisoning of fish and wildlife. Some practices outside the farmer arena to reduce Se contamination would be management of mining operations and control of fly ash from coal-fired power plants.

SUMMARY

Consider the Se hazard to man, livestock, fish, and wildlife when you assist a farmer or rancher build a reservoir, plan a grazing system, improve an irrigation and drainage system, construct a wetland, construct a pond, or evaluate a domestic well.

Consider the factors of Se distribution: Is the farm or ranch in an area of Cretaceous or Jurassic shale formation? An area with less than 20 inches of annual precipitation? Is seleniferous vegetation, such as loco weed, present? or Do ground water and surface water quality records indicate Se?

Consider the conservation practices or auxiliary actions that can be taken to prevent chronic or acute poisoning of humans, livestock, or fish and wildlife by selenium. Also, be prepared to make recommendations to overcome selenium deficiencies.

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APPENDIX - Distribution of Selenium in the West

Geologic distribution of Se. Selenium is widely distributed in the earth's crust, is most common in Cretaceous shales, and is associated with sulfide minerals. Millions of years ago, much of the West was covered by marine and non-marine seas and resulted in deposits containing salts and Se.

There is a strong association between Se concentrating vegetation and outcrops of Jurassic and Cretaceous Formations. These formations were deposited 200 to 66 million years ago. A **geologic map** showing the distribution of these formations is included as Figure 3. Many geologic formations, such as Niobrara, Pierre, Fort Union, Bearpaw, Mesaverde, Mancos, Ogellala, Wasatch, Moenkopi, Chinle, and Kayenta are seleniferous and capable of contributing to the mobile forms of Se in soils.

Solubility of Se in soils. The presence of Se in geologic formations does not mean it is present in toxic amounts in the soils derived from these strata. The solubility of Se in soils is dependent on pH, moisture, oxidation-reduction conditions, and the degree of aeration. Under arid, alkaline, and generally well aerated conditions in the West, Se in the soil may be mobilized in its oxidized, and readily soluble, selenate form. A **precipitation map** showing the portion of the West with less than 20 inches of annual precipitation is shown in Figure 4. When precipitation exceeds 20 inches and there is deep percolation, Se is slowly leached and is not concentrated in the soil. Ground water can become contaminated from leached Se.

The amount of Se in the soil is not a reliable indicator of that which is available to plants or that can be leached by deep percolation. In moist, acidic, and reducing soils, Se is present as insoluble selenides, elemental Se, or insoluble pyritic selenites and not available to plants. Under dry, alkaline conditions with seleniferous-derived soils, microorganisms produce selenates and organic Se complexes which are very soluble. Excess precipitation or irrigation water draining these soils would leach soluble selenites and selenates and also carry dissolved and suspended organic forms of Se.

Selenium concentrating vegetation. The ability of different plant species to uptake Se from the soil, accumulate and tolerate it varies widely. Selenium can be bio-accumulated by Se-concentrating vegetation such as Astragalus (24 species - loco weed and milkvetch), Machaeranthera (Thistle), Haplopappus (Goldenweed), and Stanleya (Mustard). These plant species have an extraordinary ability to acquire Se, and can absorb high concentrations of Se that may be hundreds or even thousands of **mg Se/kg or parts per million (ppm)**, dry weight. A **vegetative map** showing the distribution of these plants in the West is included as Figure 5.

Selenium in mining operations. Selenium is closely associated with uranium (U), bentonite, and coal mining. There is a potential for contamination of soils, surface waters, and ground waters in and adjacent to these mining operations. The highest concentrations of Se reported for soils and geological material are associated with U deposits. Concentrations as high as 4500 mg/kg have been reported in the overburden from the Powder River district in Wyoming. Selenium-concentrating vegetation was used as a botanical prospecting tool in the 1950's (Cannon). The location of uranium mining in Arizona, New Mexico, Colorado, Utah, Wyoming, and Montana is an indication of high concentrations of several trace elements and include As, Cu, Mo, Pb, and Se. A **uranium mining map** of 4600 operations is included as Figure 6 to indicate the distribution of high concentrations of Se.

Bentonite mining in Wyoming, Montana, and South Dakota are additional Se sources. Bentonite was formed from volcanic ash deposited about 75 million years ago in shallow seas. The rock formed in these Cretaceous seas was shale. The Se content of coal and carbonaceous shales may be concentrated. Increased mobility and solubility of Se can occur at coal, bentonite, and uranium mining operations.

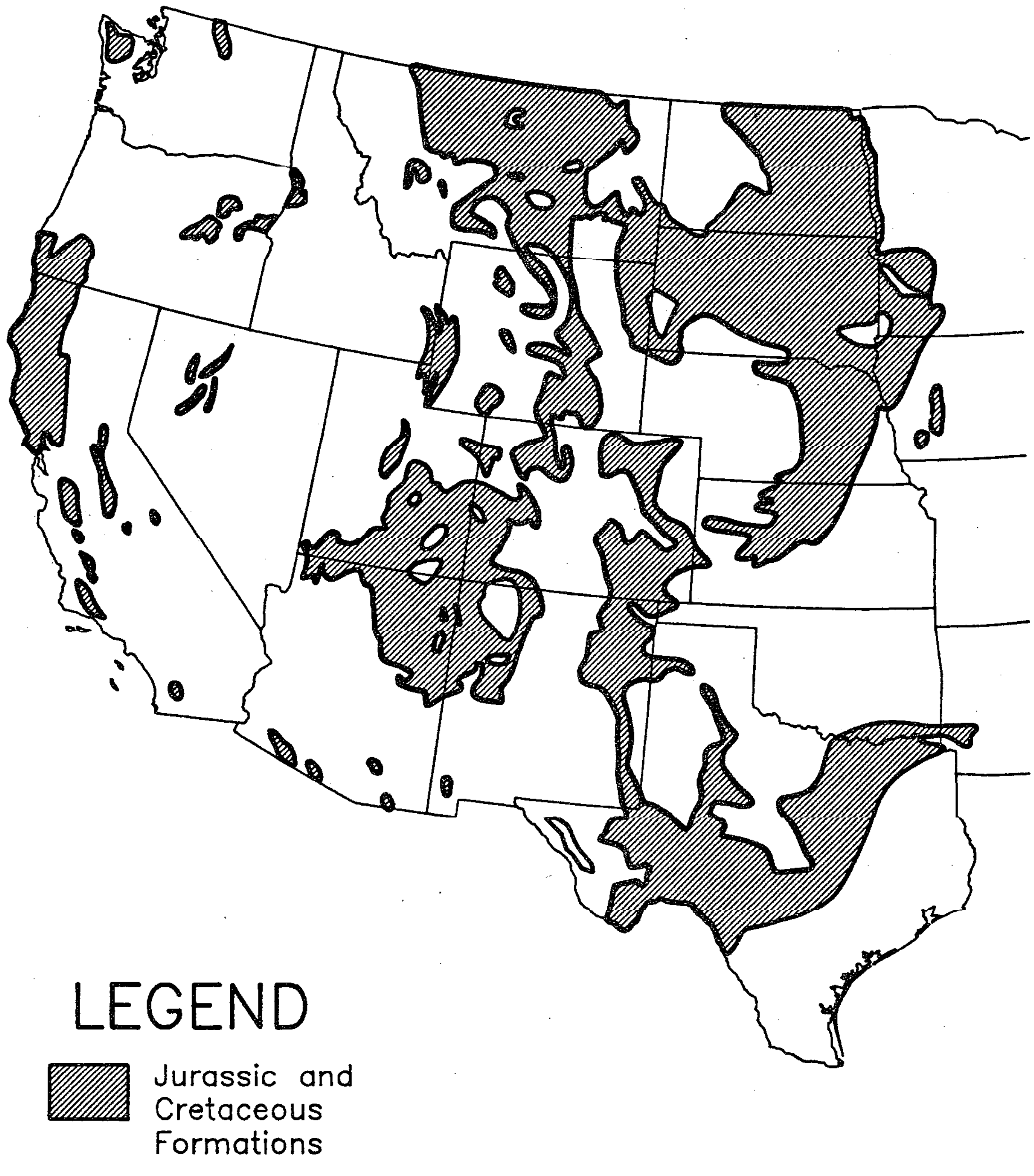

Figure 3. Selenium is widely distributed but most common in outcrops of Jurassic and Cretaceous Formations.(adapted from National Atlas, Geology Map, U.S. Dept. of Interior, Geological Survey, 1966.)

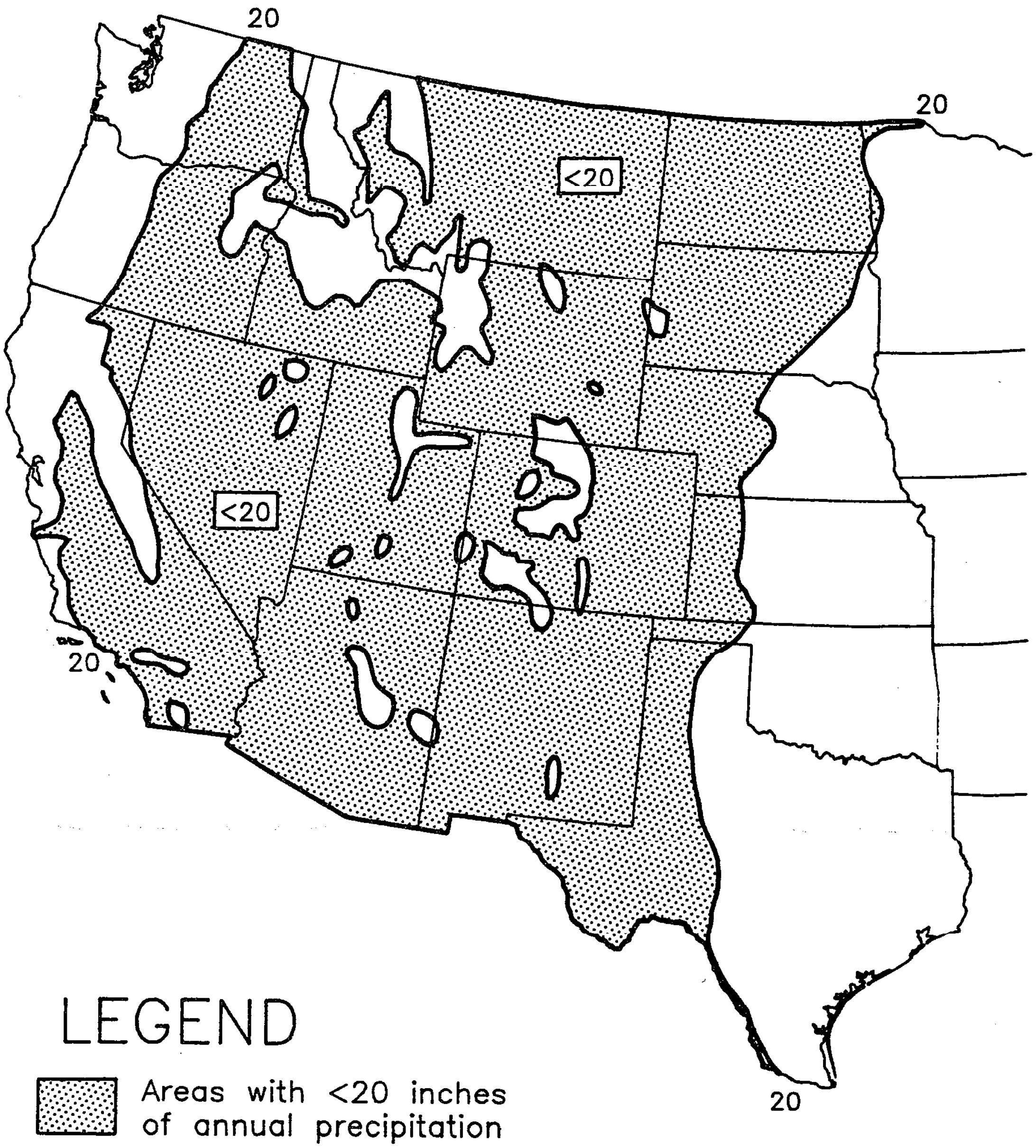

Figure 4. Areas with less than 20 inches of annual precipitation may accumulate soluble Selenium in the soil profile. (adapted from Climate Atlas of the U.S., U.S. Dept. of Commerce, Environmental Science Services Administration, Environmental Data Service, 1968.)

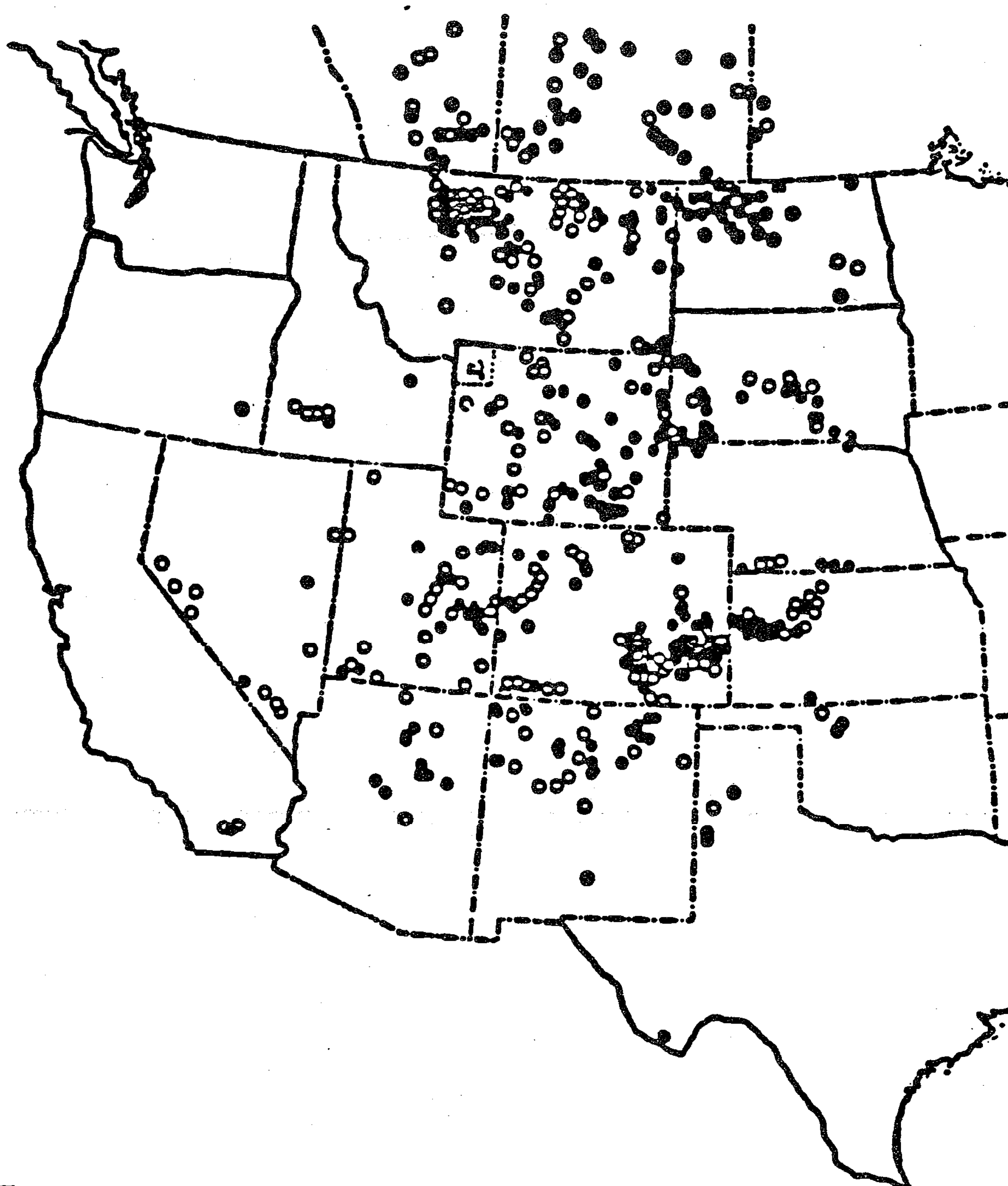

Fig. ~~2-1.~~ 5 Distribution of seleniferous vegetation in the western USA and Canada (adapted from Rosenfeld & Beath, 1964). Each open dot represents the place of collection of a plant specimen containing 50–500 mg Se/kg; each solid dot represents specimens containing >500 mg Se/kg.

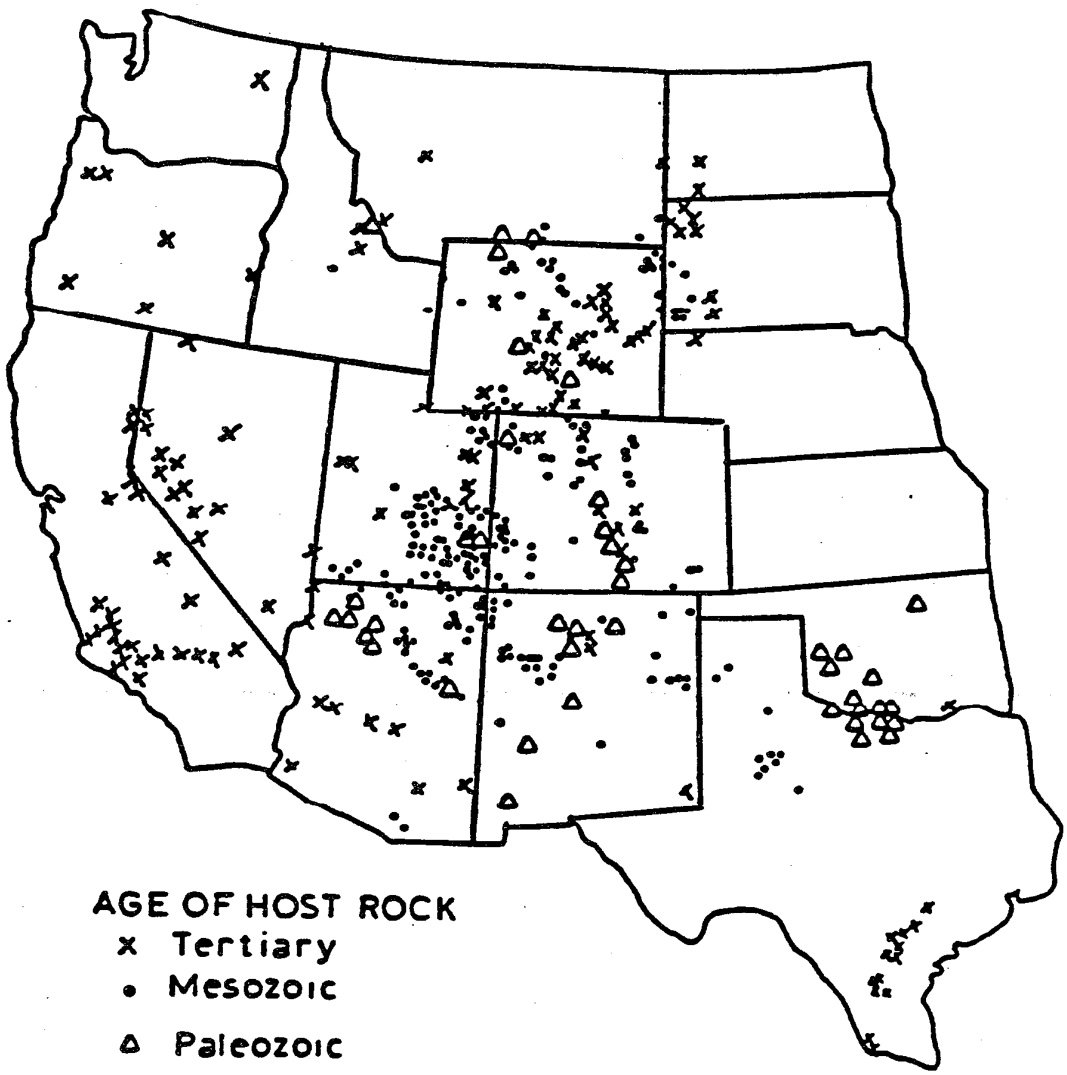

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Fig. ~~6-2~~: Uranium deposits in sandstones of the western USA (Finch, 1967).